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ON THE WHOLESOMENESS OF DRINKING WATER.

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It was only about thirty years ago that cholera epidemics were discovered to be largely due to the transmission of the disease from one person to another by means of water used for drinking. This disease is unquestionably transmitted also in other ways, as for example, by the atmosphere; but that water is one of them, and in some countries the most important one, the vital statistics of England prove beyond a doubt. I say, in some countries, not in all; for it appears that the evidence in Germany, which seems to have been very thoroughly investigated, is against the theory of the carriage by water of the cholera poison in such a way as to cause infection. Pettenkofer, the celebrated sanitary authority of Germany, is entirely opposed to this view. Nevertheless, in England, India, Holland, and a few localities in Germany, the evidence appears overwhelming. Dr. Parkes states that while we should give proper deference to the evidence in Germany and Austria, we should not allow it to outweigh the evidence from other countries.

It has also been found that typhoid fever has been spread through towns and smaller communities and through separate households by carriage of the infection by drinking-water. So many instances of this have become known that it may be considered proved beyond all possible doubt to be a fact, and one which is generally and not merely exceptionally true.

It is true, however, that typhoid fever, like cholera, may be transmitted also by the air; and there can be no question that the gases or vapors emanating from sewers and drains and breathed in a confined atmosphere are a very frequent means of transmitting the disease.

Dr. Parkes states, in the latest edition of his work, that the question which is the most important or frequent means of infection, air or water, cannot yet be answered. Dysentery has been long known to be caused partly by bad water. There is considerable evidence to show that water may transmit diphtheria, but not sufficient to prove it with

certainty, except perphaps some evidence in Massachusetts which is very strong.

When the water in any of these cases has been examined by chemical tests it has generally been found to have organic matter either dissolved up in it or suspended in it. Frequently this material has been found so entirely dissolved as not to be detected by the eye; that is to say, water which was clear, colorless, free from anything visible, except a very few floating particles and which even had a good, refreshing taste, was found on careful examination of all the circumstances to be without the slightest doubt the real cause of the spread of typhoid fever and cholera from one person to another.

Water, on the other hand, which is pure or free from any contamination with human sewage, in any part of its history in past or present time, has never been proved to be the means of infection with such diseases as cholera and typhoid fever. But diseases of other sorts have been caused by mineral matters dissolved in the water or by vegetable matter held in suspension, while the water was nevertheless entirely free from sewage contamination.

Water, then, which is impure, is to be dreaded as a frequent cause of disease. But in what does this impurity consist and how are we to distinguish the two sorts of impurity I have mentioned? We will understand this better if we first carefully consider what constitutes a naturally pure water and which is found, by wide experience, to be perfectly wholesome and should be our daily drink.

Those who have studied chemistry are aware that absolutely pure water is composed of one part by weight of hydrogen to eight parts by weight of oxygen, or, by volume, of two parts of the former to one part of the latter. Chemically pure water contains nothing else whatever. But such water does not exist in nature, nor can it probably be produced in the chemical laboratory, for the purest distilled water, redistilled many times, is found, perhaps invariably, to contain exceedingly minute traces of ammonia and on standing a few hours it absorbs oxygen and nitrogen from the air to which it is exposed.

When, therefore, we speak of a pure, wholesome water we do not mean water which is chemically pure, but one which is as free from foreign substances as is to be found under the most favorable natural conditions.

We should consider all natural water found either on or below the surface of the ground as having been originally precipitated out of the

atmosphere in the form of rain, snow, hail, fog or dew. Of these, rain and snow are obviously the most important, and these in falling carry down with them a part of whatever may be either naturally or abnormally present in the atmosphere. Now, we know by practical experience that the atmosphere in high situations is generally purer than on level plains or in low places. When our bodies are in need of an invigorating atmosphere we go to the mountains, and those who have traveled in mountainous regions often speak of the delightful effects experienced, provided they do not enter too rare an atmosphere. Chemical analysis confirms this impression. The atmosphere of the mountain is generally really purer than that of the valley at its foot.

Rain collected near the surface of the earth will, therefore, be more impure than that collected at a considerable height, because of the greater impurity of the air near the surface of the ground. After the elapse of a short time the rain water will be much purer than during the first part of the time of rainfall.

The purest air of the mountain regions contains, besides nitrogen and oxygen, a small proportion of carbonic acid in the free state and still smaller amounts of ammonia combined with carbonic acid, nitric acid and nitrous acid. Besides these, there is found also a very small amount of organic matter suspended in the air, probably dead or effete matter swept up by currents from living animals and from vegetation in decay. The amount of this organic dust becomes less and less as we ascend to greater heights, while the proportion of carbonic acid becomes somewhat increased. All of these various gaseous and solid substances are therefore to be found in rain water. Since a part of the rain goes to form springs, we find these substances in the purest spring-waters; but here they exist in a somewhat different form from that which they had in rain. Water in passing through the ground always comes in contact with some substances capable of dissolving more or less in it.

Water in its purest state may be said to be an almost universal solvent. Give it sufficient time and the proper temperature and atmospheric pressure and it will dissolve an appreciable amount of the most insoluble substances. This effect will take place much more readily when the water contains certain saline substances, especially nitrates and chlorides. When rain water has carried down from the atmosphere salts of ammonia, even if in very minute amounts, its solvent power on soil and rock is thereby increased, and this increase will be

in some proportion to the amount of impurity washed out of the atmosphere.

The soil itself is known to contain carbonic acid in its pores in much larger proportion to the other gases than exists in the atmosphere. Carbonic acid, we all know, is soluble in water in greater amount, according to the pressure, as is well shown in the soda-water fountain. This gas when dissolved in water has a great solvent power on limestone rock, and when the carbonic acid gas escapes again by evaporation the water leaves those beautiful pendant stony icicles which we find in limestone caves like the Mammoth Cave of Kentucky and which we see on a very small scale on the arched roof of many stone bridges, where they are formed from the mortar between the stones of the arch. In fact, the caves themselves are thought to be formed by this solvent action. Lime is a part of the material of many other kinds of rocks beside limestone and of the soil resulting from their disintegration. The gaseous carbonic acid of the soil added to that already in the rain and to the nitrous and nitric acids in combination with ammonia also found in it, dissolve a part of the lime and other mineral matter of the soil and rock, and when this soluble mineral matter is in large amount a mineral spring is formed thereby or simply an ordinary limestone spring, as the case may be. In either case the water is called "hard." If the rock is of insoluble material like granite or gneiss, only a very small part of it is dissolved, and in this case a soft spring water is formed. Yet even in granitic regions the water may be hard, owing to such substances as sulphate of lime in the soil above the rock being dissolved in it. This is to a certain extent the case in Germantown, where some of the uncontaminated wells furnish quite a hard water while others give very soft water.

All soils contain more or less organic matter derived from vegetable and animal matter in decay. Some of this will necessarily go into solution and pass into the spring water; but it appears that some spring waters contain less organic matter than the rain from which they are derived, so that there is possibly a filtering action going on in the soil in these cases. In the majority of cases, however, it is probable and in many cases, it is certain, that a proportion of the organic material of the soil is added to that already in the rain. The amount of organic matter in soil and rock varies according to its geological nature. Thus, such rocks as the granitic series contain almost no organic matter, while sands and gravels, sometimes thought very free from it,

generally contain considerable amounts of it, and occasionally in so large amounts as to cause the well waters to be decidedly injurious. Dr. Parkes mentions as an instance of this the district in the South of France called the "Landes," where the sandy soil contains so much as to cause water of that region to produce malarial fever.

Alluvial soil, or that deposited by the floods of rivers and streams, contains very frequently large amounts of organic matter which passes into springs and wells and renders them unwholesome.

Waters from marshes are well known to contain large amounts of vegetable organic matter, so as often to prove extremely unwholesome. The case of the ship *Argo*, sailing in 1834 from Algiers to Marseilles, may be mentioned as a very strong instance in proof of this.

Water coming from peat bogs is often highly colored with dissolved peaty matter. This peaty matter appears to be very different from the vegetable matter found in marsh water in not being in a state of actual decomposition, but being material which has in the solid state become partially carbonized and undergone thereby a change preparatory to becoming coal. Hence a number of chemists and sanitary officers have of late years strongly protested against the condemnation of peaty waters on the same grounds as marsh waters, declaring this to be a great mistake. It must be admitted by every candid student of this subject that some waters, which experience has proved to be very wholesome, originate in peat bogs and contain in the state used for drinking very considerable amounts of nitrogenous organic matter in solution, and there is evidence to show that this material is mainly of vegetable origin.

Let us now consider the effects produced on the health by the mineral matter commonly present in ordinary spring and river waters under entirely natural conditions. While we can positively say that our present knowledge does not warrant the assertion that any one of a number of these mineral substances have any injurious influence upon the health, it is nevertheless obviously true that a large excess of lime and magnesium salts, such as carbonates, sulphates and chlorides, are undoubtedly unwholesome in many instances.

Waters which contain these salts of lime and magnesia are called "hard" in consequence of their action on soap. The great waste of soap caused by these waters as well as their injurious influence in the boiling of meats and vegetables are matters of considerable importance in domestic economy. The soap waste and the tendency to

form incrustations in boilers are facts of vast importance to the manufacturer, but these considerations we will postpone for the present.

While dyspepsia and other internal maladies have undoubtedly been traced to the drinking of water containing large amounts of these salts and while goitre and cretinism occur in close connection with, and some affirm, are caused by magnesian limestone waters, there seems to be still a decided disagreement among sanitary authorities as to the wholesomeness of a moderately hard water. Hardness, however, which is due chiefly to sulphate of magnesia, would seem certainly undesirable on several accounts.

From these circumstances it will appear evident that the purest water naturally contains some appreciable amounts of mineral matter, and a water which does not contain it in too large amount, the limit of which has not been satisfactorily settled, may correctly be considered, so far as this is concerned, a perfectly pure water from a strictly sanitary point of view.

Finally, from this whole discussion it is clearly seen that a hygienically pure water must be defined as one which may contain naturally foreign substances, both mineral and organic, in small amounts; but if the organic matter is in larger amounts it must not be in a state of decay or decomposition or capable of readily undergoing such changes.

Further consideration will lead us to modify this statement in so far as to add, that a pure water must also contain nothing which would leave a suspicion upon the mind of a probable present or future contamination with sewage.

Some authorities would add that it also must contain no evidence of contamination with sewage *in any past time.* This is the position which Dr. Edward Frankland takes; but I think we may reasonably dissent from so severe a decision, which would exclude all our river waters as too dangerous for public supply. The chief reason for dissenting is that the premises upon which he founds his conclusions have not been clearly proven, indeed, they are directly disputed by other chemists.

We have heretofore considered water as it exists under wholly natural conditions. We will now consider it as these conditions are influenced by man's occupations and habits which are consequences or accompaniments of civilized life, and interpose circumstances more or less artificial.

We have noticed the influence which the natural atmosphere has on

the chemical condition of rain water. What is now the effect of the atmosphere surrounding communities of men?

The atmosphere of cities and towns is rendered impure by the gases, smoke and soot issuing from the chimneys of houses and factories; by the dust from the streets, which is to a great extent organic; by particles of all sorts of clothing, hair, skin and refuse material from every trade; organic matter from the breath and persons of men and animals; and also by the gases resulting from decomposition of organic matter such as garbage and filth usually left for some time in places where it should not be at all, and the gases arising from stagnant sewers.

Rain, in falling through such an atmosphere, will wash down these gases and organic dust, thereby rendering the atmosphere more fit to dwell in. But the rain water itself will be exceedingly impure, and, indeed, so foul as to be entirely undrinkable without nausea. Beside the organic matter, nitric, sulphuric and muriatic acids, in the free state as well as combined, are found in such rain in considerable amount, which will vary greatly. In addition to the effete or dead organic matter we find also in the air minute forms of animal and vegetable life. Nevertheless, the air of well ventilated streets, even in large cities, is much purer than we might expect. The percentage of oxygen in many streets in the less crowded parts of London, that is to say, outside of the limits of old London, was found very slightly less, and the percentage of carbonic acid very slightly greater, than the natural amount on open land.

Rain falling in suburban towns will, of course, be much purer than that of cities; but where the houses are situated near much-traveled streets, dust composed largely of organic matter will be deposited on the roof, and the rain water collected from this will contain considerable impurity.

If the gutters and pipes placed to carry the water into cisterns, or the cisterns themselves, are made of lead or zinc, these metals will be dissolved by the water so as to render the cistern water poisonous to drink. This corroding action is commonly much more rapid with rain water than with ordinary spring water.

If we pass on to the consideration of other kinds of drinking water, we find that streams, ponds and rivers, all of which are used for this purpose, contain the dissolved manure from cultivated fields, and the filthy and often very poisonous drainage from factories of

various kinds, besides those which make use of chemicals in their processes of manufacture. In addition to these, a most important source of impurity, and wherein lies probably by far the greatest danger, is the sewage of cities and towns situated along the banks of rivers or lakes used for drinking water, or on streams draining into them. Frequent reference is made to the solid impurities, such as wool factory refuse, floating on the surface, but any one who is acquainted with the methods used for cleansing the raw wool knows the disgusting character of the materials used for this purpose, enormous volumes of which are poured into the river after the operation is finished, and which are probably entirely unseen because dissolved in the water. It may be said, however, that much of this organic stuff may be entirely decomposed and destroyed before it passes through the water mains and is delivered to consumers. We hear frequent remarks made on the impropriety and danger of allowing cemeteries of large extent, like Laurel Hill, to drain into a river water used for drinking. The dangers arising from this source may, however, be said to be infinitesimal as compared with the direct drainage of human bowel excreta into the river by means of city sewers. The peculiar dangers of sewage contamination of public water supplies will be more clearly understood as we discuss the subject in subsequent lectures of this course.

Wells are the chief source of drinking water in country and suburban districts, and in towns having no public water supply. Artesian wells of great depth are sometimes used for city supply, but these are found unsatisfactory, because they do not meet the demands of an increasing population, and at the same time generally furnish a very hard water.

Deep wells, or those over 100 feet in depth, but not artesian, are seldom used for private domestic purposes, yet these are strongly advocated by high sanitary authorities, as furnishing the best supply for domestic use where a "driven" tube well cannot be sunk. The chief object is to go below and to exclude carefully the water in the upper water-bearing strata, which will be very liable to become impure. The wells generally used are less than fifty feet deep, and very frequently both these wells and the vaults and sinks for sewage are generally placed tolerably near the house, and also near each other. Often in small lots, and sometimes in larger ones, the cesspools or privies and wells are not more than ten feet apart. Ash and garbage heaps, in a state of fœtid decomposition, are frequently placed quite close to the well. All

this has been found actually true in various parts of England, and in Massachusetts.

As might be expected, numerous cases of typhoid fever were the immediate cause of the investigations that were made. Not only in Massachusetts is such culpable negligence to be found, but also in many other parts of this country, and as near home as the immediate neighborhood of Philadelphia. The recent investigations of the Massachusetts State Board of Health into the sanitary condition of hotels and boarding-houses at various summer resorts of that State has brought to light a large number of cases of most astonishing ignorance and criminal negligence in this respect on the part of both hotel proprietors and smaller householders. Some of the cases discovered on the island of Martha's Vineyard were so bad that it is difficult indeed to believe that any person would knowingly subject himself to such dangerous surroundings.

Dr. Joseph G. Pinkham, in his very able and thorough official report, in 1876, on the sanitary condition of Lynn, Mass., himself a resident of that town, makes the following remarks:

"The most erroneous ideas in regard to the liability of wells to contamination prevail among the people. Those who are familiar with the principles of under-drainage by means of porous earthen tiles know that when they are placed in the earth the water will find its way, for quite a long distance on either side to them and through their pores; yet they are only small vacant spaces in the earth, while a well is a large and deep one, attracting moisture from a much greater distance. But, notwithstanding these well known facts, persons of high intelligence on most points feel perfectly secure in regard to their wells with a cesspool or privy within a few feet of them."

In regard to other sanitary conditions, Dr. Pinkham remarks:

"Less than one-tenth part of the families, shops, etc., supplied with the city water have drains connecting with the sewers."

He estimates that drainage water to the amount of 420,000,000 gallons are annually absorbed by the soil of this town, and then he asks the reader to form his own opinion as to the probability of this foul drainage soaking into the thousands of wells situated in this same thickly settled part of the town. There is but one possible answer to the question. It is but right to add that what was true of this town in 1876 may be very much improved now, but of this I have seen no positive statement.

We know very well that any hole or ditch acts as a drain to the earth surrounding it. A well, as ordinarily constructed, is precisely such a hole for drainage. Any contaminating liquid, or any solid matter capable of being dissolved and washed into the soil by the rain; any such material as human sewage placed or allowed to flow on the surface of the ground near the well, will be exceedingly liable to pass directly into the well water. In other words, it will help feed that well, and a considerable amount of sewage escaping filtration will eventually be daily consumed by the people of the house in their drinking water.

This is certainly not a pleasant subject to contemplate, but it will do us no possible good to shut our eyes to a state of things which actually exists, and which is every day liable to cause disease and death in our families.

The more loose the soil in which the well is dug, that is to say, the more sandy and gravelly it is, the more liable the well is to contamination. It has been stated by some writers that a well drains a mass of soil in the shape of an inverted cone whose apex is the bottom of the well and whose base is an area of surface having a diameter equal to three times the depth of the well. That is, a well of 20 feet deep will drain an area 60 feet in diameter or any liquid within 30 feet of the well will be liable to pass directly into it. This statement is necessarily a very rough estimate, since the area of surface drained will vary exceedingly according to the character of the soil. There is clear and positive evidence to show that in sandy and gravelly soils the extent of drainage area is far greater, even when the surface of the ground is level and the stratification of soil is quite horizontal. In New England the Massachusetts State Board of Health Reports give a number of instances where pollution of wells from cesspools situated in sandy level soil to the distance of more than 100 feet from the wells. The water was found by chemical analysis to be polluted with sewage and cases of typhoid fever occurred from the use of such water for drinking.

If contamination takes place in level soil to the distance of 100 feet it will undoubtedly be liable to occur at much greater distances when the soil and rock are inclined towards the well. Mr. Child, Officer of Health for Oxfordshire, England, gives in one of his reports an instance of the fouling of wells by petroleum or benzine which passed through the soil from a broken barrel buried in the ground to a num-

ber of wells all of which were from 250 to 300 yards distant. The surface of the ground had a descent of about 60 feet between the two points toward the wells. About 82 people living in 15 houses were unable to use these wells for ten days and cattle refused to drink from one of them. In commenting on this remarkable case we should recollect the extraordinary penetrating power of petroleum oils. We can scarcely believe that sewage can be carried through nearly the sixth of a mile of soil as the petroleum was in this case. Nevertheless it furnishes a very good text for a sermon on the possibilities of sewage contamination.

Sand and gravel at first undoubtedly exert a certain amount of filtering power. But this is soon exhausted by the soil becoming saturated with filth, and in course of time a direct channel may be opened to the well through which the sewage may sometimes pass unobstructed even in the solid condition.

From these facts we can positively say that a sandy and gravelly subsoil is one of the most dangerous of all situations for a shallow well in a thickly settled neighborhood, or where the cesspools and privies are not placed at the distance of several hundred feet from the well.

A "tube" well, or "driven" well, will be little, if any, better whatever, unless the tube is sunk to a depth approaching one hundred feet, except in a few cases.

In addition to this we have already seen that such soils very often contain large amounts of organic matter, naturally present, and that this amount may be of itself so large as to produce malarial fever, by drinking the water. These considerations are of especial importance in regard to the well waters of southern and central New Jersey, and in regard to the possibilities of obtaining a really and permanently pure water supply, public or private, at the seaside resorts of that State, which must be considered by the sanitarian to be decidedly a doubtful matter, until careful chemical investigation can prove the contrary to be true.

It has lately been discovered in Massachusetts that some kinds of rock are no real hindrance to the direct percolation of cesspool sewage through them. In one case the well was sunk down into the solid rock for some distance, and the walls of the well were with the utmost care laid in mortar and coated with hydraulic cement from the surface of the ground down to the rock. Yet with all this care contamination took place from a cesspool on the opposite side of the house and fifty

feet distant from the well. The sewage was shown to have passed down through the rock at right angles to the dip or inclination of the rock, which was about 45°. The rock was sandstone, and percolation took place between the joints or fractures in the strata. On the removal of the cesspool to a distant part of the premises the water became decidedly better. The account of this remarkable case was published by Dr. Pinkham, of Lynn, in *Scribner's Monthly* for 1877.

From the brief study we have made of this subject in this lecture we may sum up the following conclusions to which we should carefully give practical attention.

On no account should we ever allow a cesspool, vault or surface privy within a radius from a well equal to twice its depth.

No drain pipe, whether of iron or terra cotta, should ever be allowed within this distance on account of the danger of leakage. The best laid drains have been frequently found to leak in the most unexpected places, and where especial care had been taken to prevent it.

In the case of houses on small lots of ground in a town wells ought never to be used at all for drinking. The Board of Health of such towns should have full legal power to close up all such wells, and remove the pumps, even if no positive disease has ever arisen from their use, or even if no complaint has been entered by a person residing in the immediate neighborhood. The Board of Health should also have power to prohibit any new wells being dug on premises of less than a certain fixed size.

Where a system of sewerage exists cesspools should be totally prohibited under penalty of law, unless such cesspools are built absolutely water tight, and kept so, and are thoroughly ventilated by tall pipes or chimney stacks, and the contents are frequently and regularly removed.

A certificate of compliance with these conditions given by regular official sanitary inspectors should be required at regular stated periods, say once a year, of every person having such cesspools on his premises.

No new cesspools should be allowed under penalty of law, unless by a certificate granted by a regular official sanitary inspector.

When a system of sewerage does not exist in a town the same law should be made to apply wherever the houses are not very scattered. In rural districts the law would be inapplicable.

All wells located near sewers or under street pavements, or exposed to contamination from street gutters, should be immediately closed and

the pumps removed. Such wells are extremely dangerous and a direct menace to the public health. In cases where a right of way to such a well is granted to several property holders by deed of title the Board of Health should have legal power to overcome resistance to its action so as to prevent all further use of the well, under penalty of law. A case of this kind has lately become known within the limits of Philadelphia, which I was requested to investigate.

In all cases of refusal of property holders to comply with such requisitions of the Board of Health, the latter should have power to proceed as in ordinary cases of public nuisances.

A modification of the law should be made so as to include within its prohibition all such wells as are likely, in the opinion of regularly constituted sanitary authority, to become polluted in the near future as well as those which are now actually in a polluted condition.

[In his concluding remarks the lecturer spoke of the minute living animals found in river water, and exhibited by means of the lantern several photographs of animal and vegetable life found in the water supplied to London in 1851 and 1854, which were years when cholera was violently epidemic in that city.]

These photographs are taken from plates in Dr. Hassal's work on adulteration of food. I wish to express, however, my strong dissent from the opinions of Dr. Hassel as to the injurious character of these animals and diatoms themselves. I believe that no clear and positive evidence whatever has ever been brought forward to prove with any degree of certainty these forms of life themselves to have been the cause of disease. They could not have caused cholera in London, for many of them, nearly all perhaps, are stated to be found in the Schuylkill river water at the present time, and yet Philadelphia was, at least in 1872, exceptionally free from cholera at a time when it was epidemic in other parts of the country. No disease has ever been proved attributable to these living forms in the Schuylkill river.

The chief point to be considered is, what may be associated with these animalculæ and upon which they may feed, or in some way be the indication of its presence. Some of them, undoubtedly, live only in comparatively good water, in proof of which statement, the reader is referred to the work of Dr. Macdonald on the microscopic analysis of water. Some of them require a polluted water, and one which contains sewage in not too great amount will often be crowded with some

forms, as was the case with some of the London water, which in 1851 and for some years after, was taken from the river at the London bridges, where contamination with sewage was very great.

These animalculæ, therefore, may be an indication of organic filth in the water, and this filth may be excreted from the intestines of diseased people. The animalculæ themselves are probably no more injurious to a human being than raw oysters. In all probability they can be digested with equal rapidity, and there is, as far as we know, no possible way for them to get into the blood in a living state.

[Photographs were also exhibited of the fresh-water algæ which were the cause of the disagreeable pig-pen odor in the Boston water a few years ago. These were from plates drawn by Prof. Farlow, of Harvard, for his paper in the Massachusetts State Board of Health Report for 1879.]